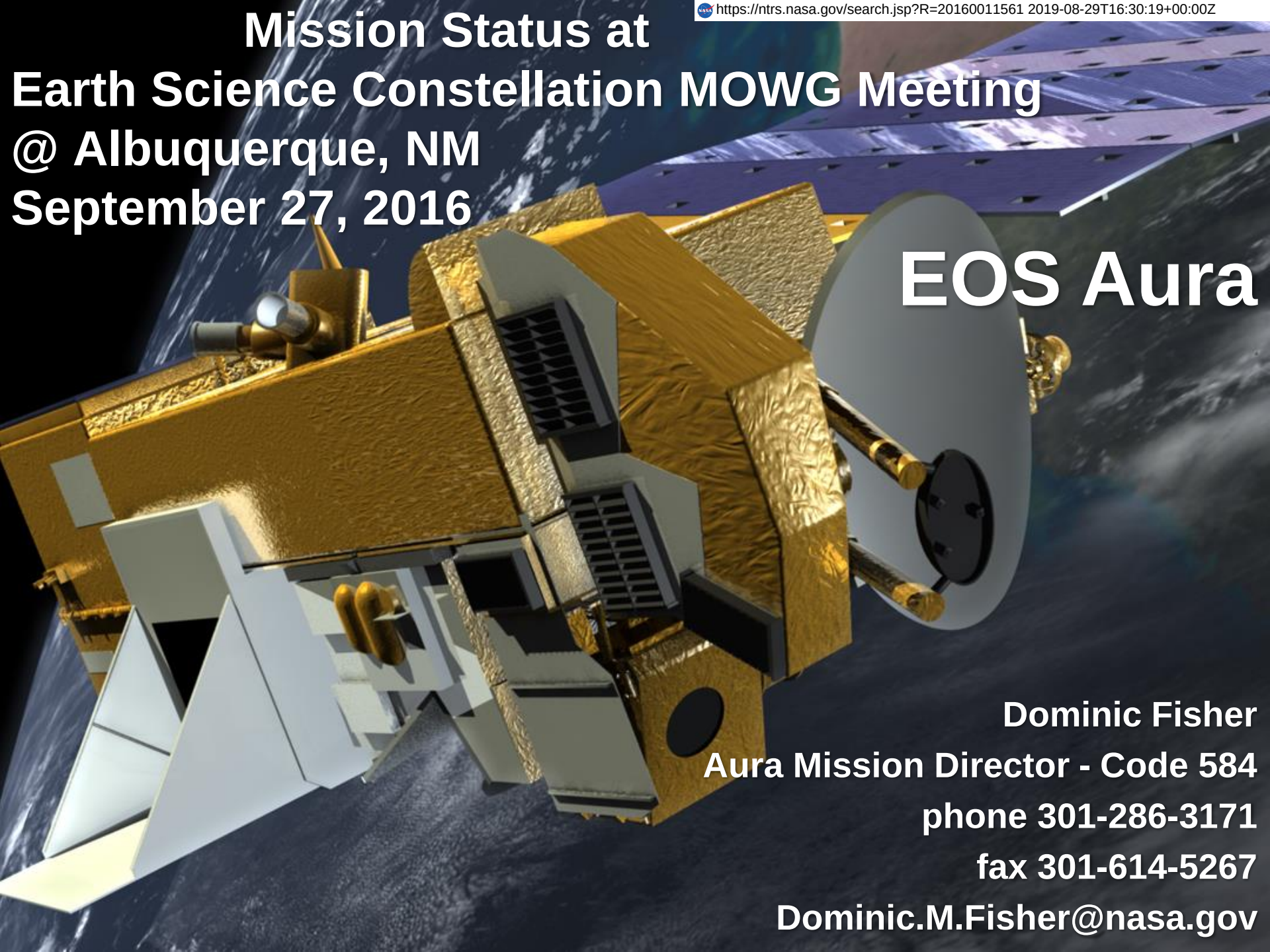
Mission Status at Earth Science Constellation MOWG Meeting @ Albuquerque, NM September 27, 2016



EOS Aura

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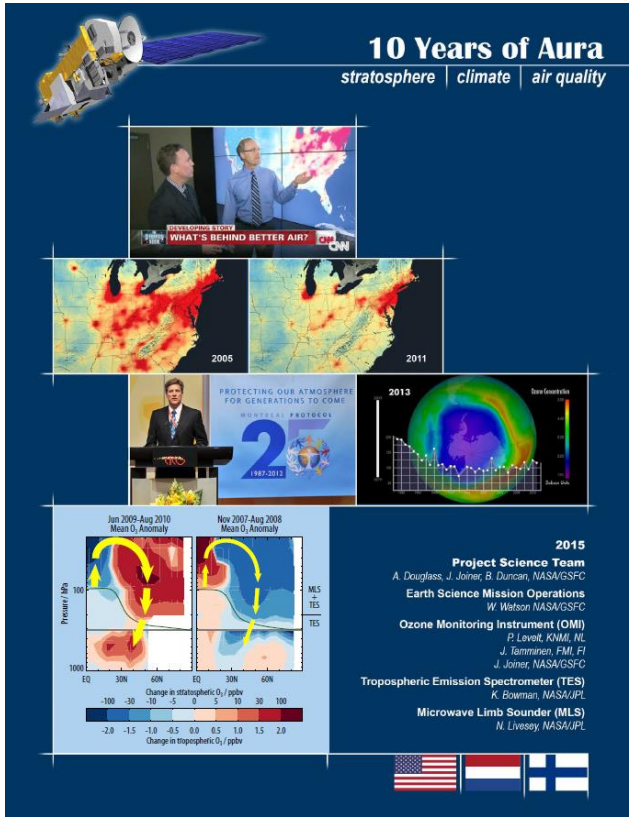
Topics

- **Mission Summary**
- **Spacecraft Subsystems Summary**
- **Recent Activities**
- **Planned Activities**
  - **CRMS Process Improvement**
  - **Spring 2017 IAM Draft Schedule**
- **Propellant Usage & Lifetime Estimates**
  - **FDS Decommissioning Analysis**
  - **End of Mission Plan (EOMP)**
- **Overall Summary**
- **Additional Slides:**
  - **Spacecraft Maneuvers & Ground Track History**
  - **HIEs, Data Capture, & Ops Error Statistics**

EOS Aura Mission Summary

(Updates since April 2016 MOWG in Boulder, CO)

- 07/15/04: Launch
  - 6-Year Design Life
- 09/30/10: End of Prime Mission Review
- 03/04/15: Senior Review Proposal #4
  - Reliability Estimates through 2021
  - Consumables through 2022
- 09/18/15: 2015 Mission Extension Senior Review Proposal Panel Report
  - #4 Ranked Earth Science Mission
  - Mission extension through FY17
- 01/27/16: ESMO Annual Review #9
- 07/15/16: Aura 12-Year Anniversary



Aura Spacecraft Subsystems

(Updates since April 2016 MOWG in Boulder, CO)

- **Command & Data Handling (CDH) – Nominal**
  - ***Solid State Recorder (SSR) Anomaly (December 4-18, 2007)***
    - » ***Returned November 2010 at reduced level – then subsided January 2011***
    - » ***Returned again 04/15/2012 – currently still "active"***
- **Communications (COMM) – Nominal**
- **Electrical Power System (EPS) – Nominal**
  - ***Solar Panel Connector Anomaly – ARE-3C (January 12, 2005)***
  - ***Solar Array Offset (Reported 11/17/09, Corrected 06/29/10 and each year since)***
  - ***Array Regulator Electronics (ARE) 5A Anomaly (03/12/2010 & 04/25/2013)***
    - » ***03/12/2010: Simultaneous with GN&C Attitude Disturbance – attributed to MMOD Strike***
  - ***Other older ARE Anomalies:***

    ARE-5C (9/27/12 & 2/4/13), ARE-1A (3/12/10 & 11/5/11), ARE-6A (9/14/13), & ARE-4A (12/08/14)
    - » ***Estimated that Aura has lost 25 strings of solar cells out of a total of 132 strings***
    - » ***Aura continues to have significant power margin where the life limiting item is fuel***
- **Flight Software (FSW) – Nominal**
- **Guidance, Navigation & Control (GN&C) – Nominal**
  - ***Earth Sensor Assembly (ESA) Anomaly (05/29/2009 & 06/13/16) – Re-calibrated in Nov. 2009 & Aug. 2016***
- **Propulsion (PROP) – Nominal**
  - ***Dual Thruster Module (DTM-3) Anomaly (Aug 16, 2005)***
- **Thermal Control System (TCS) – Nominal**

All subsystems configured to primary hardware

Recent Activities

(April 2016 – September 2016)

- **5 CARA High Interest Orbital Debris Events (Tiers 1-4)**
  - **0 required significant action (T3 / T4)**
  - **Last significant actions: DAM 1/18/16, DAM 3/15/16, DAM Waived 3/17/16**
- **1 Minor Spacecraft Bus Anomaly**
  - **Earth Sensor Assembly (ESA) Anomaly (6/13/16) – Updated threshold 8/18/16**
- **7 Significant instrument related anomalies (Generated NASA Anomaly Reports)**
  - **TES: 4 ICS Motor Stall Events (7/20/16, 8/1/16, 8/4/16, 8/15/16),**
  - **1 Instrument Safe Mode Event (8/19/16)**
  - **OMI: 1 Instrument Survival Event (5/29/16), 1 Instrument Safe Event (6/10/16)**
- **6 Spacecraft Maneuvers:**
  - **4 Routine Drag Make-up Maneuvers (DMUMs):**
    - » 2016: 5/26 (#92), 6/23 (#93), 7/28 (#94) and 8/31 (#95)
  - **2 Inclination Adjust Maneuvers (IAMs):**
    - » 2016: 4/7 (#47) and 4/21 (#48),
    - » The other Spring 2016 IAMs, #45 (3/10) & #46 (3/23), weren't included in this reporting period
- **0 Instrument Calibration Maneuvers**
  - **Next MLS Yaw & Moon Scan: Spring 2017**

Planned Activities

- **October 2016: Drag Make Up Maneuver (DMUM) #96**
- **November 2016: Updated Decommissioning Plan**
- **December 2016: Updated Reliability & Lifetime Estimates**
- **January 2017: Flight Operations Annual Review (#10)**
- **January 2017: Updated End of Mission Plan (EOMP)**
- **February 2017: Extended Mission Senior Review Proposal**
- **Spring 2017: A-Train Science Symposium (4/19-21/2017 - Pasadena, CA)**
- **Spring 2017: Annual Inclination Adjust Maneuvers (DRAFT SCHEDULE)**
  - 3/02/17 (#49), 3/09/17 (#50), 3/23/17 (#51), & 3/30/17 (#52)
- **Spring 2017: Earth Science Constellation (ESC) MOWG (Dates TBD – GSFC, MD)**
  - Update propellant budget, decommissioning analysis, reliability predictions,…

- **Mid-to-Long-Term Plans**
  - **Continue to improve RMM / DAM execution**
    - » See additional details on CA automation (CRMS) in the following slide
  - **EOS Automation (EA) – automation of routine operations**

Collision Risk Management System Process Improvements

- In response to the constantly increasing number of predicted close approaches with orbital debris and operational satellites (High Interest Events – HIEs) and anticipated updates to the US Air Force Space Fence which will significantly increase size of the Space Catalog (20K ➔ 150-200K)

- ESMO has been developing new ground system capabilities to autonomously identify and develop maneuver options to assist in Debris Avoidance Maneuver (DAM) planning

- Collision Risk Management System (CRMS) capabilities will include:
  - Goal is to develop an automated debris avoidance maneuver planning process
  - User defined collision risk thresholds
  - Maneuver optimization to address multiple conjunctions with secondary object conjunctions

- EOC is currently operating with CRMS Release 4.0 (ΔORR 8/24/16)

DRAFT Spring 2017
Inclination Adjust Plan

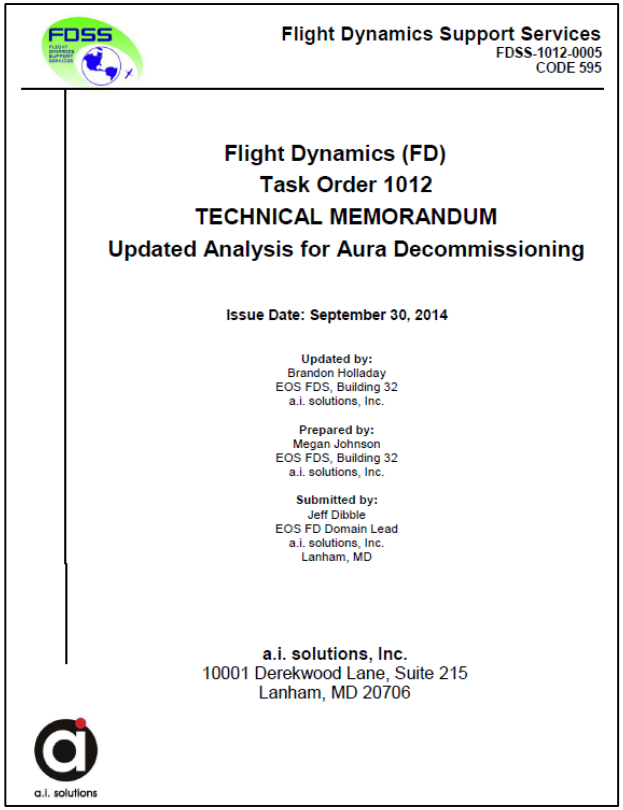
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
19 **Feb**	20	21	22	23	24	25
26	27	28	1 March **Aqua IAM #52**	2 **Aura IAM #49**	3	4
5	6	7	8 **Aqua IAM #53**	9 **Aura IAM #50**	10	11
12	13	14	15 **Spring Break**	16 **Spring Break**	17	18
19	20	21	22 **Aqua IAM #54**	23 **Aura IAM #51**	24	25
26	27	28	29 **Aqua IAM #55**	30 **Aura IAM #52**	31	1 **April**
2	3	4	5 **Aqua Backup**	6 **Aura Backup**	7	8
9	10	11	12	13	14	15
16 **Easter**	17	18	19	20	21	22

A-Train Science Symposium in Pasadena, CA

Aura Propellant Usage
(Update expected September 2016)

- **2006: Initial Aura lifetime fuel analysis**
- **2008: Detailed Aqua & Aura lifetime analysis**
  - Presented to MOWG and at Aura End of Prime Mission Review in September 2010
- **2012 (September): Initial Aura Decommissioning Plan**
  - Updated Lifetime Estimates
- **2013 (August): Updated Decommissioning Plan**
  - Updated propellant trends for IAMs & DMUMs
  - Updated definitive fuel usage and predicted solar flux levels
  - Updated Constellation Exit Plan
    - Safely exiting the Afternoon Constellation requires that Aura's final apogee be at least two kilometers below the minimum perigee of the other constellation members (692 km target)
    - Perform orbit lowering maneuvers centered at apogee and perigee (pairs of maneuvers)
- **2014 (September): Updated Decommissioning Plan**
  - Updated propellant trends for IAMs & DMUMs
  - Updated definitive fuel usage and predicted solar flux levels
- **2015 (September): Decommission Plan Update Postponed**
  - Postponed to allow additional time to evaluate long-term plan and decommissioning maneuvers
- **2016 (September): Updated Decommission Plan**
  - Investigating potential retrograde maneuver options and lifetime extending options

- **Annual updates will be provided each September**
  - Final will be produced 60 days before start of decommissioning



FOSS

Flight Dynamics Support Services
FDSS-1012-0005
CODE 595

Flight Dynamics (FD)
Task Order 1012
TECHNICAL MEMORANDUM
Updated Analysis for Aura Decommissioning

Issue Date: September 30, 2014

Updated by:
Brandon Holladay
EOS FDS, Building 32
a.i. solutions, Inc.

Prepared by:
Megan Johnson
EOS FDS, Building 32
a.i. solutions, Inc.

Submitted by:
Jeff Dibble
EOS FD Domain Lead
a.i. solutions, Inc.
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a.i. solutions, Inc.
10001 Derekwood Lane, Suite 215
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a.i. solutions

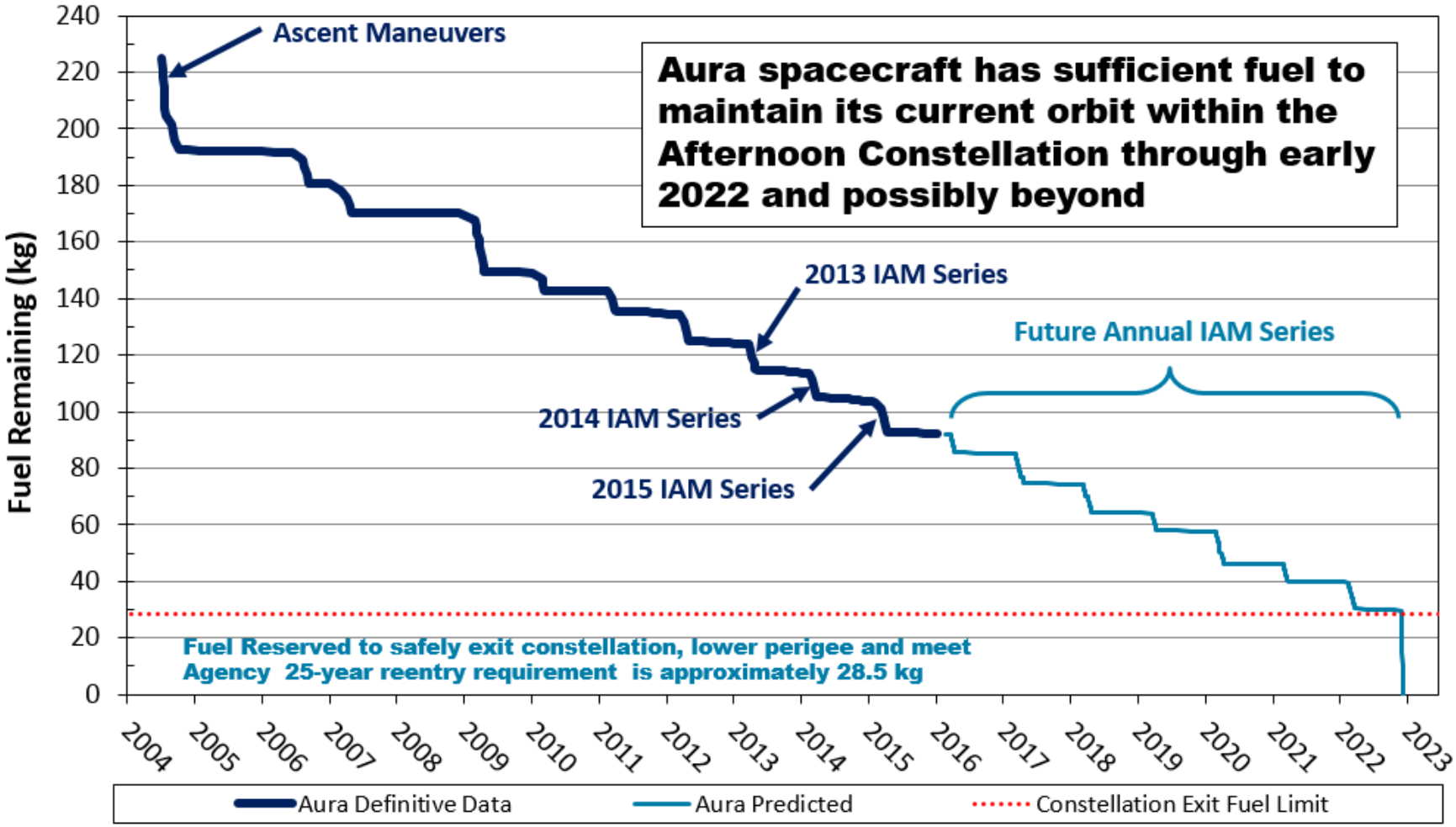
Remaining Fuel Estimate

(Update expected September 2016)

- Long-term orbit simulations were run for Aura through Feb 2023
  - Used mean nominal Schatten solar flux predictions
  - Estimated the frequency of drag make-up maneuvers to maintain Aura's WRS-2 ground track requirements
  - Estimated the required number of annual inclination maneuvers for Aura to maintain it's mean local time (MLT) requirement
  - Did not include potential debris avoidance maneuvers
  - Utilized FreeFlyer 6.7.2 which incorporated the solid earth tide model allowing greater accuracy for long term predictions of inclination, beta angle, and mean local time
- Lifetime predictions for Aura show that the spacecraft will have sufficient fuel to maintain its current orbit within the Afternoon Constellation through at least early 2022* and possibly beyond
- Analyses are updated annually by ESMO Flight Dynamics Team
  - Currently investigating various retrograde maneuver options and inclination/mean local time options to extend the potential lifetime

*** 2022 estimate based on 2014 analysis**

Fuel Usage: Actual & Predicted
(Updated January, 2016)

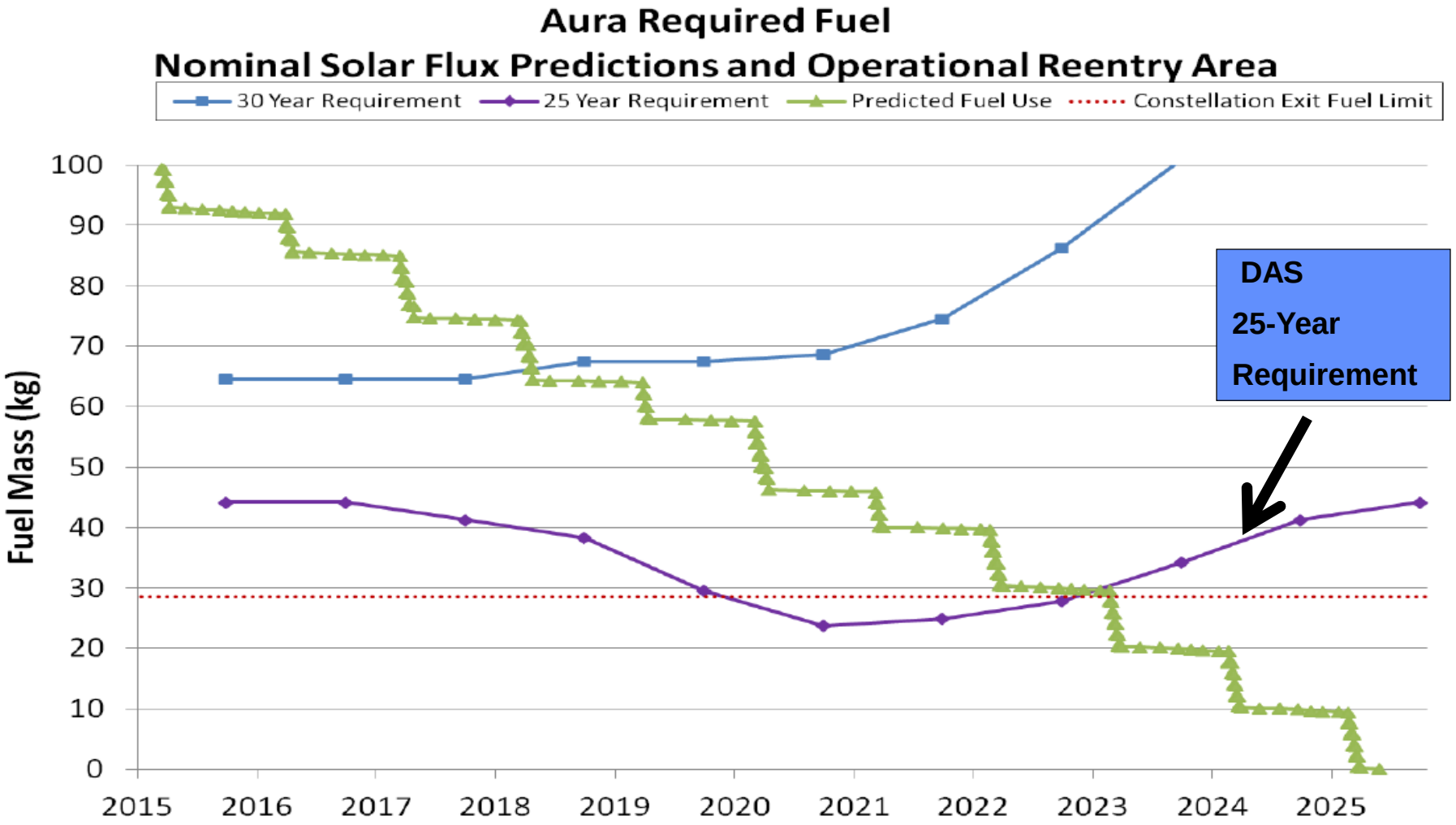


Debris Assessment Software
(September 2014 – No Changes or Updates)

- The Debris Assessment Software (DAS) was created by the Orbital Debris Office in Johnson Space Center and is the Agency standard for end of mission life analyses and lifetime estimations
  - Current Version 2.0.2
- DAS requires several inputs describing the spacecraft's mission:
  - The operational orbit parameters
  - The mission launch date
  - Length of a mission's lifetime
- In turn, DAS outputs:
  - If the mission is compliant with NASA requirements for limiting orbital debris
  - A recommended apogee and perigee that will allow the spacecraft to reenter within a specific period and satisfy NASA requirements
- Aura will have enough fuel onboard to safely exit the constellation and de-orbit to the DAS recommended perigee out through the 2023 time frame

Aura DAS End of Life Predictions

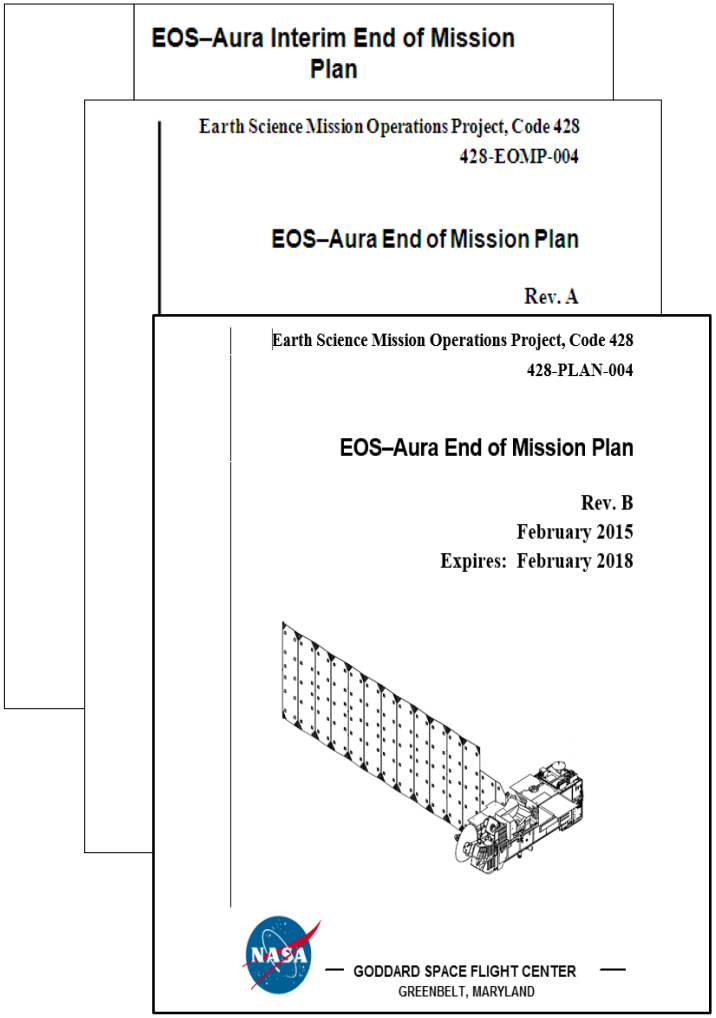
(September 2014 – No Changes or Updates)



Aura End of Mission Plan (EOMP)

(No Changes or Updates)

- **Initial draft February 2009**
- **Produced the first "Interim" End of Mission Plan (EoMP) in May 2011**
  - **Approved by NASA HQ July 2011**
- **Produced EoMP (Rev A): February 2013**
  - **Updated Lifetime Estimates (09/2012)**
  - **Added Small Object Collision Assessment**
- **Produced EoMP Rev B: February 2015**
  - **Final will be produced 60 days before EoM**
  - **Latest Annual Lifetime Estimate (09/2014)**
  - **Synopsis**
    - » Safely exit the A-Train Constellation
    - » Passivate Aura to the extent possible for uncontrolled reentry
    - » Aura has **five (5)** approved waivers for passivation
      - Pressurant Passivation
      - Large Object Collision Probability
      - Small Object Collision Probability
      - Orbital Lifetime (30-Year)
      - Re-entry Risk (Un-controlled)
    - » **Waivers were approved in May 2013**
- **Next End of Mission Plan (Rev C): Feb 2017**



Summary

- **Spacecraft Status - GREEN**
- **Instrument Status - GREEN**
  - **HIRDLS: Chopper Stalled 03/17/08 – Not collecting science data**
  - **MLS: Operating Normally – Only periodic Band 13 measurements**
    - » **08/06/13: Band 12 Shut down (reached end of useful life – 2-year design)**
    - » **THz module in Standby Mode – Tested Annually – Latest: 08/18/14 - 09/30/14**
    - » **01/02/2016: R2_GUNNBIAS_V Yellow Alarms (due to aging, limit changes TBD)**
  - **OMI: Operating Normally**
    - » **Field-of-View Anomaly started in September 2007 – currently stable**
    - » **03/03/16: OMI-IAM Command Reject Anomaly – recovered 03/16/16**
    - » **05/29/16: OMI Survival Mode Transition (Recovered 06/09/16)**
    - » **06/10/16: OMI Safe Mode Transition (Recovered 06/13/16)**
  - **TES: Modified Normal Operations**
    - » **03/27/16: TES Power on Reset (POR) Anomaly**
    - » **08/08/16: TES Laser B End of Life (EOL), transitioned to SIMCLK mode of science**
    - » **TES ICS Stalls (#7, 7/20/16), (#8, 8/1/16), (#9, 8/4/16), and (#10, 8/15/16)**
    - » **08/19/16: TES Safe Mode Event – ICS over-current triggered fault management**
- **Data Capture/L0 Processing Status – GREEN**
  - **SSR Data Capture to 07/30/2016: 99.99552737%**
- **Ground Systems – Responding to new security requirements and upgrades to obsolete hardware or COTS systems, as required – Automation efforts are underway**

Additional Charts

Maneuvers & Ground Track History
Orbital Trends

Aura Conjunction Assessment
High Interest Events (HIEs)

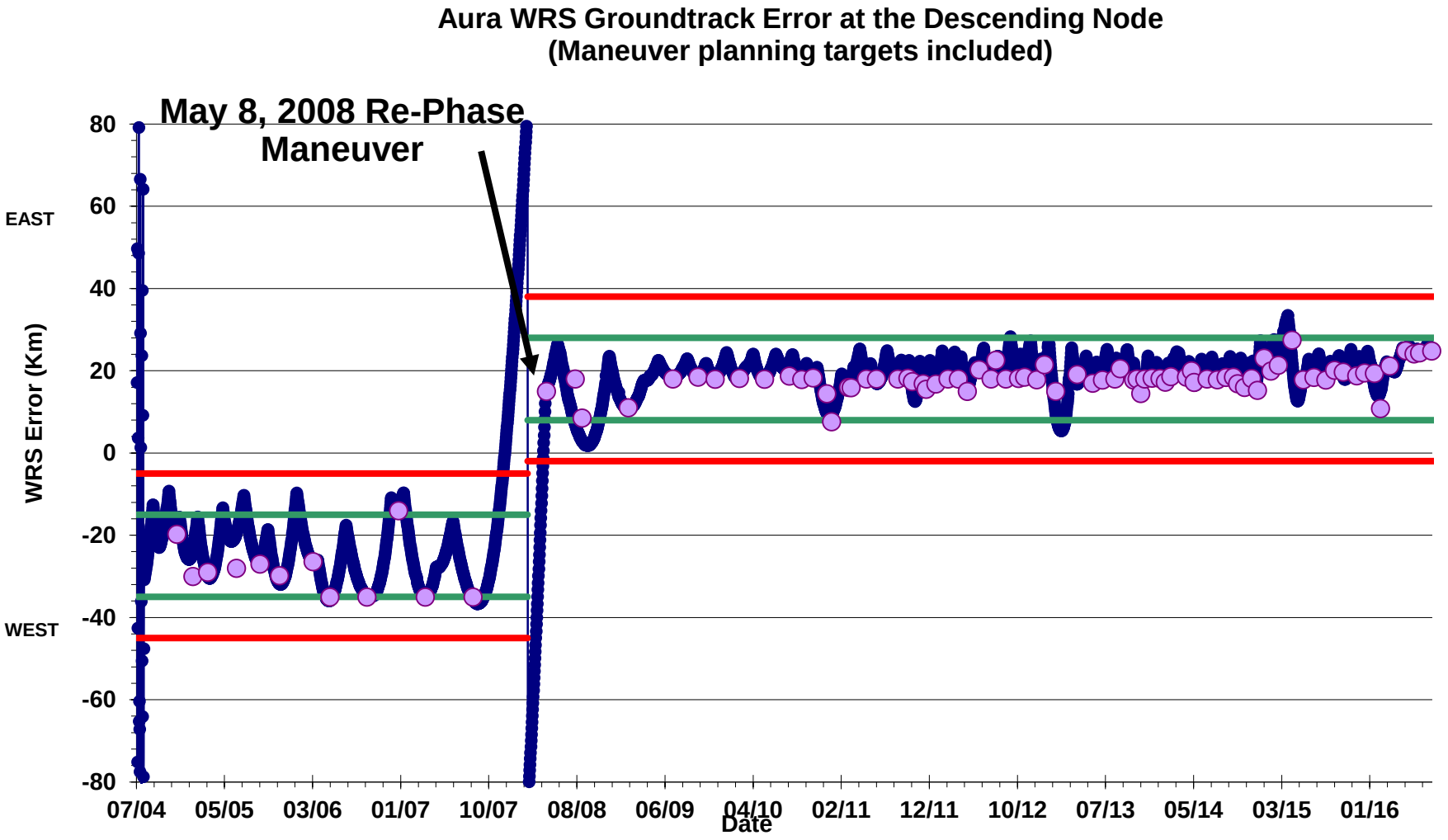
Data Capture & Operations Errors

Orbit Maintenance

- **Mission Requirements: Perform Drag Make-Up Maneuvers (DMUMs) to maintain Aura's Ground Track Error (GTE) with respect to the World Reference System (WRS-2)**
  - **Requirement: +/-20 Km as measured at the Descending Node**
- **To meet coincident viewing requirements, Aura's initial ground track was offset from Aqua's by one WRS path plus 25.4 Km**
  - **Aura was maintained -5.4 to -45.4 Km west of Aqua until late 2007**
  - **Since May 8, 2008, a new control box, +/- 10 Km from a +18 Km (east) offset of the Aqua WRS-2 path is used to maintain MLS-CALIPSO viewing request**
- **To date a total of 94 routine DMUMs have been performed**
  - **07/19/2012: DMUM # 43 No Yaw Slew Maneuver (NYS) #1 – NYS Maneuvers (37)**
  - **Last maneuver 07/28/2016 (#94) – Next maneuver 08/31/2016 (#95)**
  - **Variation in performance from –3.5% (cold) to +3.3% (hot)**
- **Conducted 11 series of inclination adjustment maneuvers**
  - **Fall '04 (4), Fall '06 (4 of 6), Spring '07 (4), Spring '09 (9), Spring '10 (3),**
  - **Spring '11 (3), Spring '12 (4), Spring '13 (4), Spring '14 (4), Spring '15 (5), Spring '16 (4)**
  - **Variation in performance from -4.5% (cold) to +1.9% (hot)**

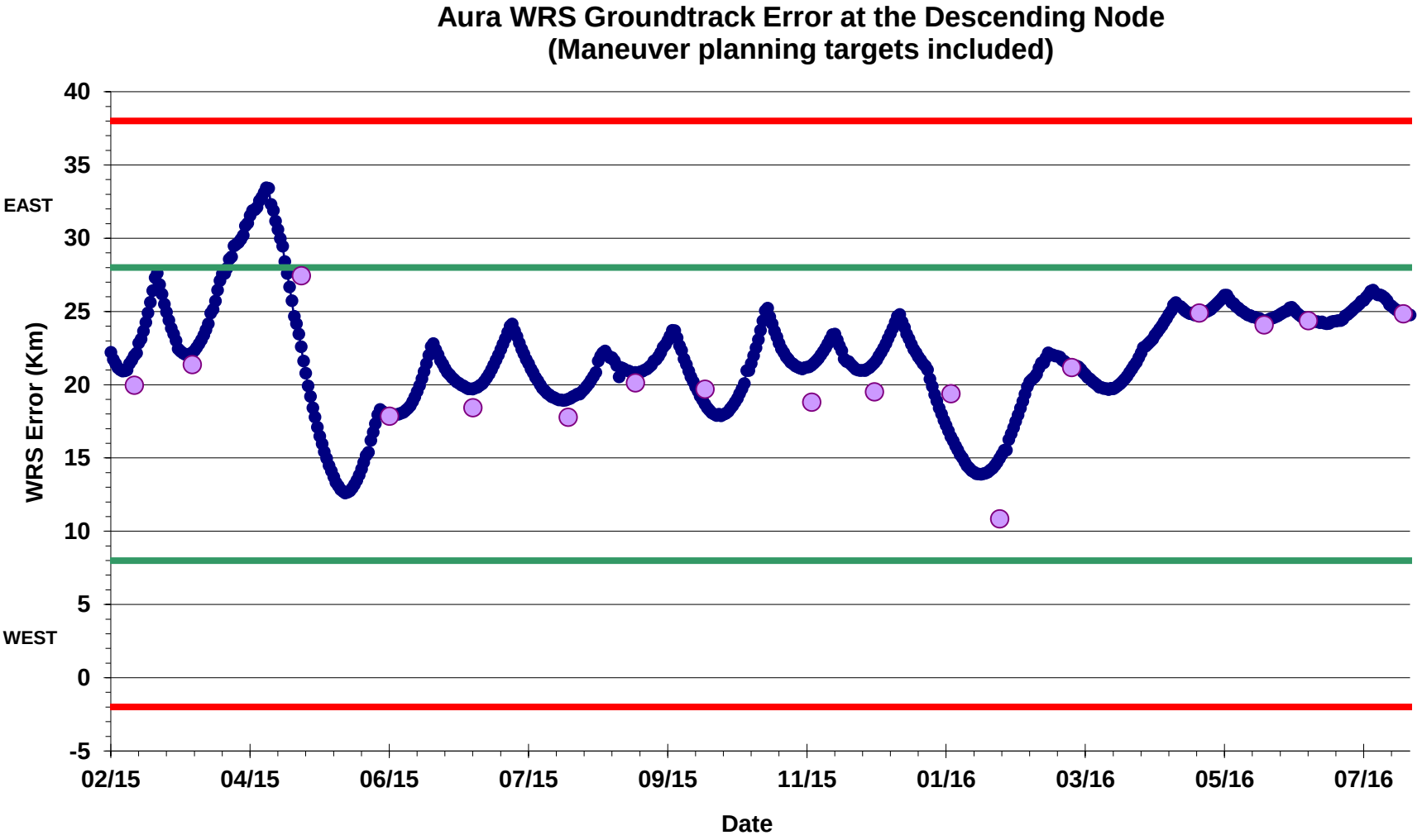
WRS Ground Track Error (GTE)

(As of August 15, 2016)



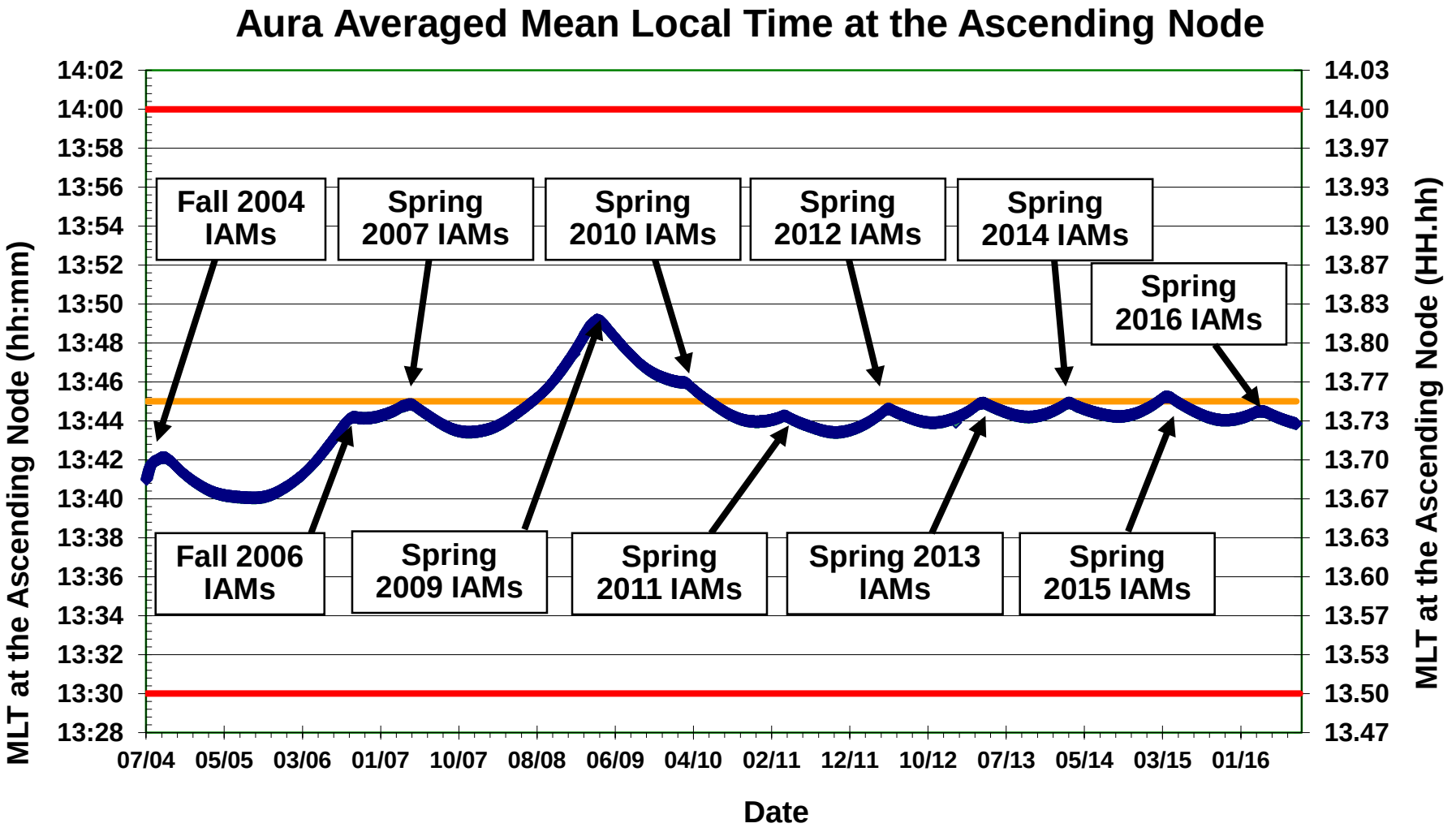
WRS Ground Track Error (GTE)

(As of August 15, 2016) Past 18+ months



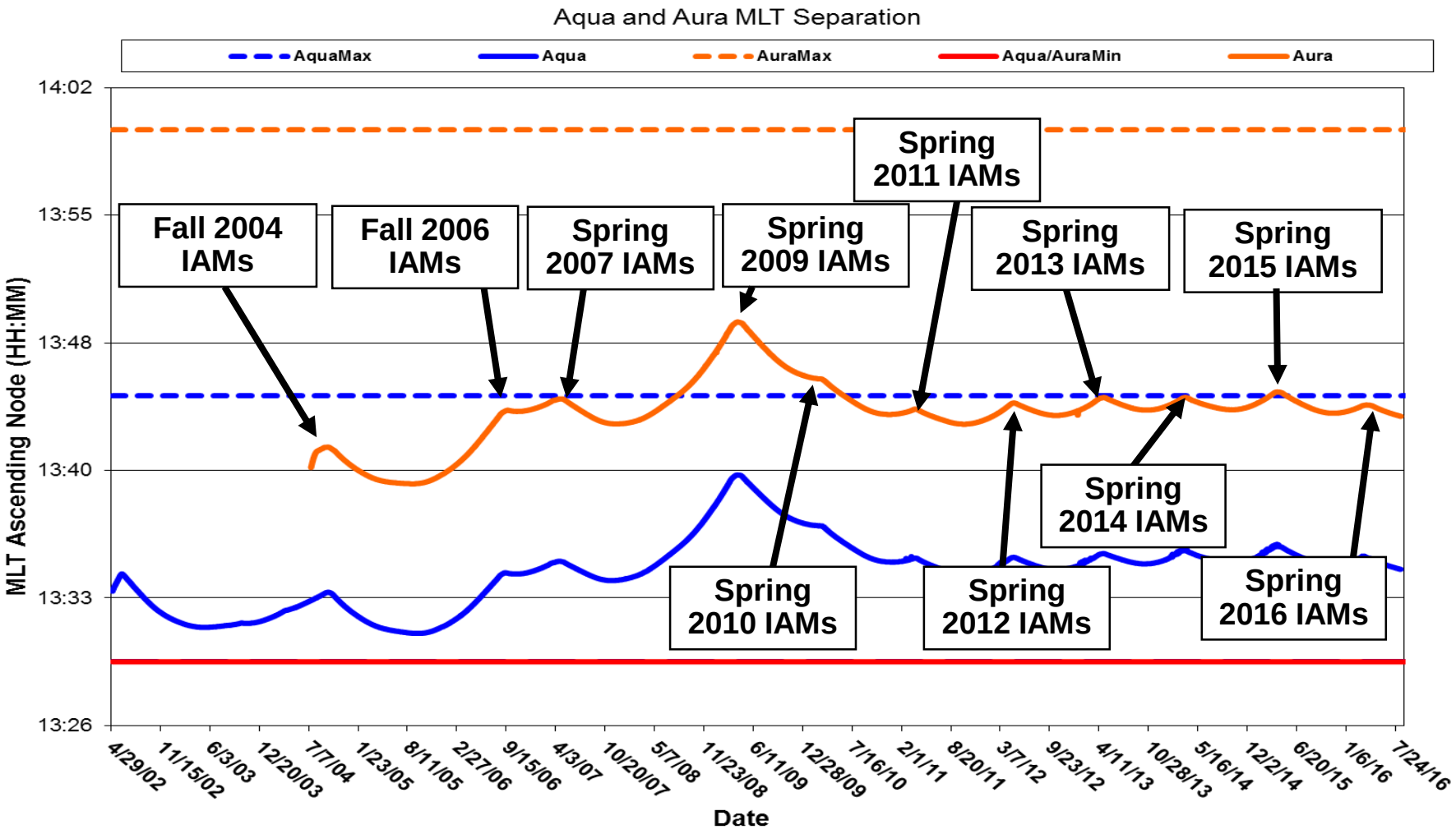
Aura Averaged MLT @ Ascending Node

(As of August 15, 2016)

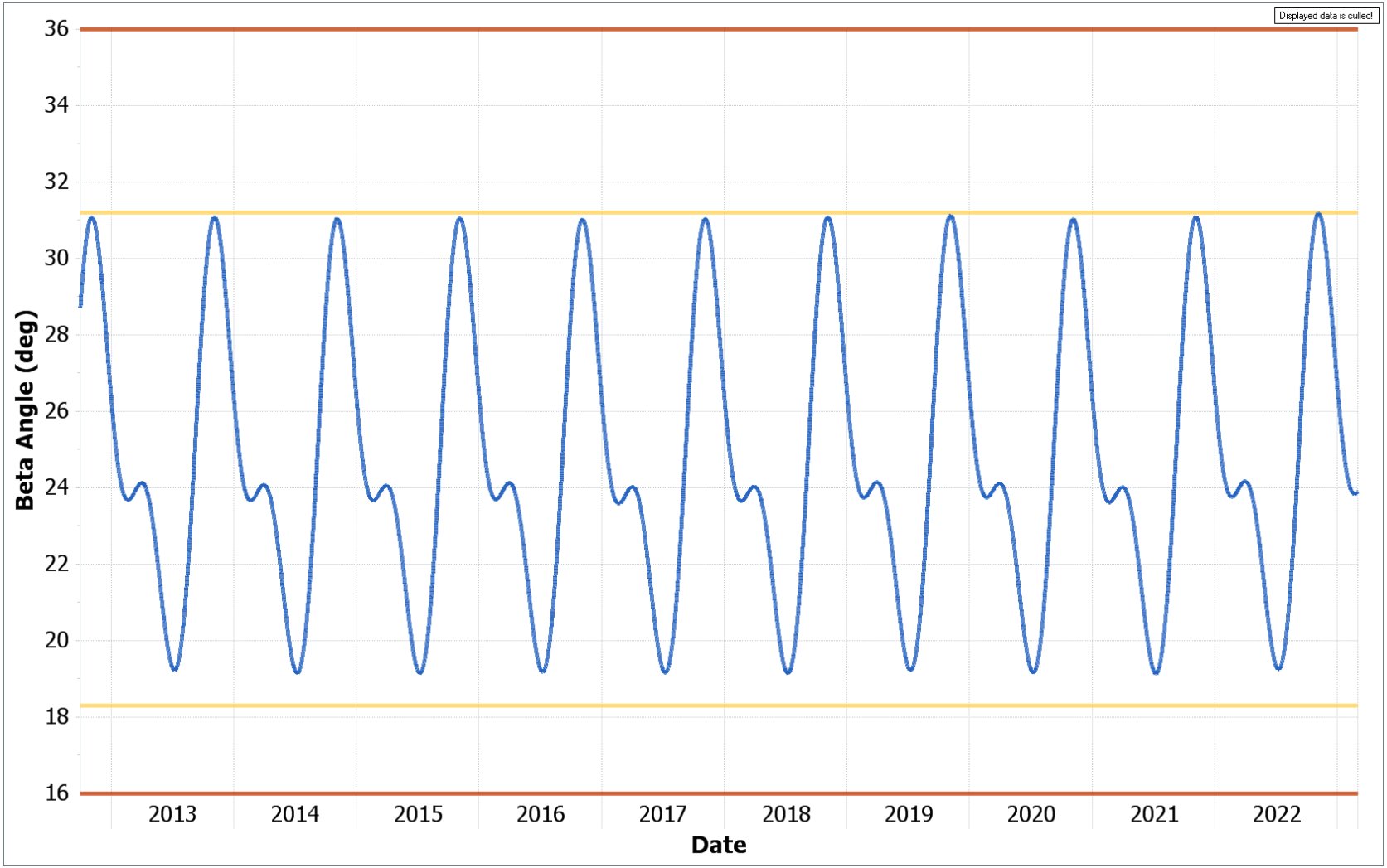


Aqua/Aura Mean Local Time (MLT)

@ Ascending Node (as of August 15, 2016)



Aura Predicted Beta Angle
(With Yearly Inclination Maneuvers)

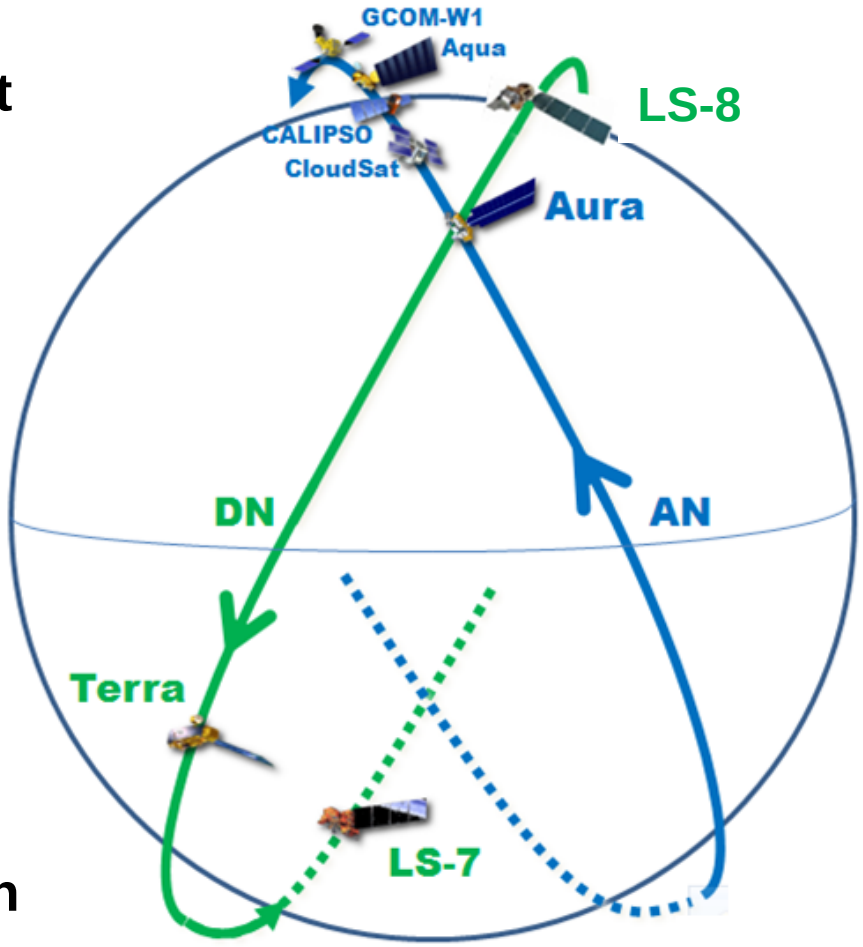


Aura and Landsat-8 (LS-8)
Orbit Phasing

With Aura in the intersection point LS-8 will be ~ 77 seconds away from the intersection Point worse case

Typically 330 – 190 seconds

Terra ~ 30 min behind LS-7

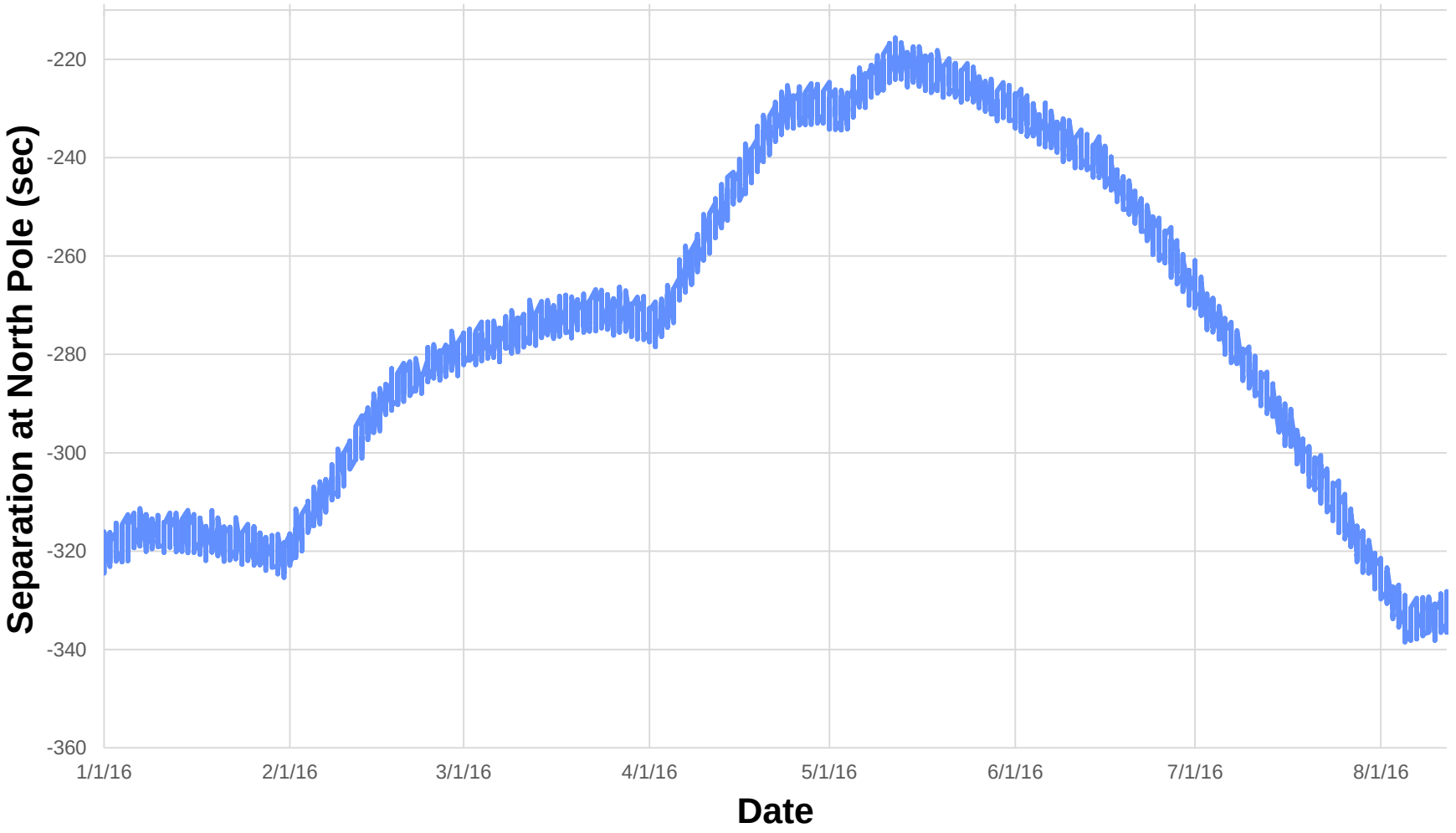


1 Orbit = ~ 100 minutes

By Design – LS-8 and LS-7 are ½ orbit apart

LS-8/Aura Phasing at Poles

@ Northern Intersection Point (as of August 15, 2016)



Aura Conjunction Assessment

High Interest Events (HIEs)

2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Tier 1	3	0	3	1	0	0	0						7
Tier 2	1	2	1	1	1	1	1						8
Tier 3	0	0	1	0	0	0	0						1
Tier 4	1	0	1	0	0	0	0						2
Total	5	2	6	2	1	1	1						18

2013: 29 CARA HIEs – 14 required significant action (T2-T4)
2014: 33 CARA HIEs – 18 required significant action (T2-T4)
2015: 32 CARA HIEs – 18 required significant action (T2-T4)

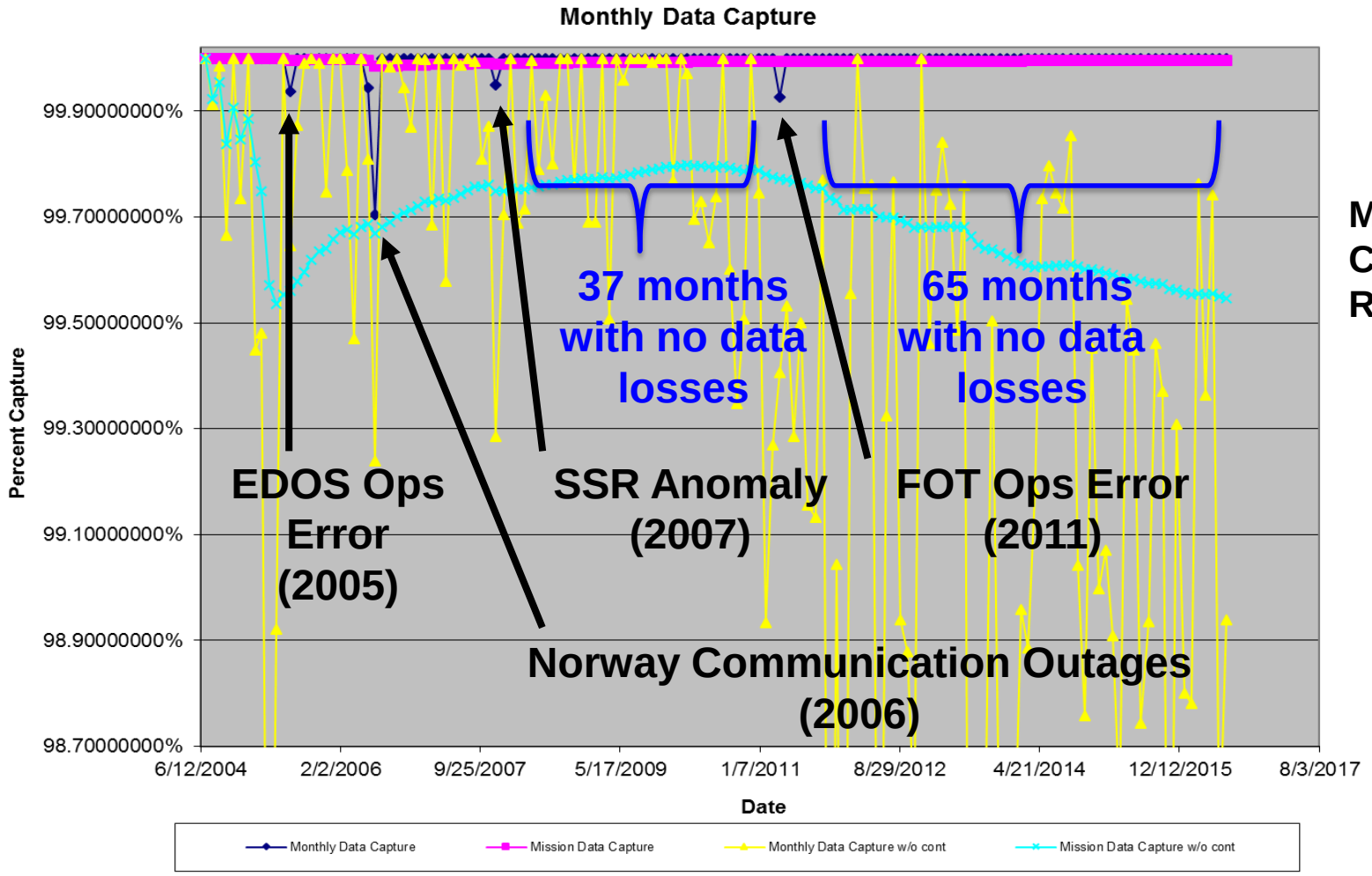
Tier 1 – Notify (email/phone), Tier 2 – Conduct Briefing,
Tier 3 – Plan Maneuver, Tier 4 – Execute Maneuver

2016: 18 CARA HIEs (thru 07/21/2016) – 11 required significant monitoring and/or actions (T2-T4)

1. **01/05/2016: CA vs. 8063 on 01/07 at 13:10:54 GMT – Considered modifying planned DMU, Pc rolled off, no action req'd (T2)**
2. **01/18/2016: CA vs. 37770 on 01/19 at 02:16:20 GMT – Executed DAM (DMU #88) (T4)**
3. **02/05/2016: CA vs. 82292 on 02/10 at 01:54:30 GMT – Monitored but no action required (T2)**
4. **02/10/2016: CA vs. 32102 on 02/12 at 04:39:52 GMT – Monitored but no action required (T2)**
5. **03/12/2016: CA vs. 39842 on 03/12 at 08:07:07 GMT – Post-IAM, monitored but no modification required (T2)**
6. **03/15/2016: CA vs. 34726 on 03/16 at 08:27:49 GMT – Executed DAM (DMU #90) (T4)**
7. **03/17/2016: CA vs. 37549 on 3/17 at 23:20:48 GMT – Planned/Approved DAM, waived-off maneuver (T3)**
8. **04/10/2016: CA vs. 35991 on 04/11 at 12:15:55 GMT – Monitored and reviewed MTS plot but no action required (T2)**
9. **05/02/2016: CA vs. 28950 on 05/07 at 16:18:47 GMT – Monitored post-maneuver conjunction for DMU #91 on 5/4 (T2)**
10. **06/10/2016: CA vs. 35858 on 06/11 at 21:46:49 GMT – Monitored but no action required (T2)**
11. **07/20/2016: CA vs. 89223 on 07/21 at 07:51:35 GMT – Monitored but no action required (T2)**

Monthly Data Capture

SSR Data Capture to 07/31/2016: 99.99552737%

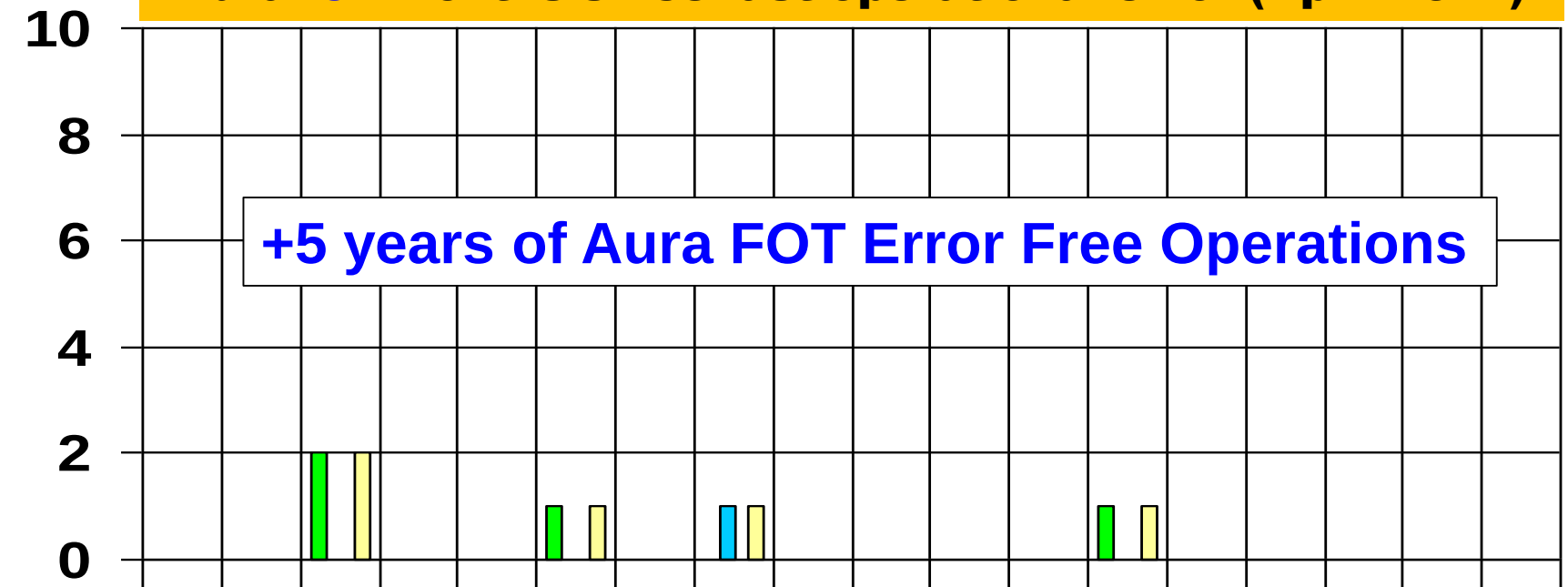


Mission Capture Req. = 95%

Operational Errors

(18-Months: February 2015 – July 2016)

Aura: 64 Months since last operational error (April 2011)



	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
Terra	0	0	2	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0
Aqua	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Aura	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	2	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0

Questions